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PATENT APPLICATION

Method and Apparatus For Optical Signal Processing Using Subcarrier Multiplexed Headers

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STATEMENT AS TO RIGHTS TO INVENTIONS MADE UNDER FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

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CROSS-REFERENCES TO RELATED APPLICATIONS

[02] The present application claims benefit of Provisional Application No.: 60/276,632 filed March 15, 2001. All material from that application is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[03] This invention relates to optical signal processing and more particularly to methods and apparatus for manipulating a SCM/mixed baseband optical signal by extracting and rewriting its subcarrier multiplexed (SCM) header signal and routing the baseband signal on the basis of the data contained in the SCM header.

[04] While the integration of data networking and optical networking is a key to the next generation optical Internet, all-optical signal processing techniques involving optical headers are still premature for practical system applications. All-optical signal routing control has been suggested through the technique of Optical Label switching. Optical Label switching incorporates a short optical label at wavelengths adjacent a data signal wavelength, the label containing routing information in its modulation. There are two key challenges in implementing Optical-Label switching systems and routers. First there is a stringent requirement for viable optical header processing and optical switching technologies, specifically, optical label switching networks will require a simple and effective method to swap headers in real time without affecting the data payload in order to achieve low-latency packet forwarding and routing. Second, there is the challenge of involving as little electronic processing as possible. Subcarrier multiplexed (SCM) header techniques meet both these requirements by allowing relatively easy separation of the of the subcarrier header from the baseband data payload compared to conventional time domain header techniques.

[05] Separation of the SCM header from the baseband data payload is achieved in the art by operations either in the electrical domain after optical to electrical conversion or directly in the optical domain. A method is known for optically filtering a single side-band (SSB) SCM header. This optical domain method requires the use of a sophisticated SSB-SCM transmitter design involving quadrature modulation of a dual-arm $LiNbO_3$ modulator. However, it is not adapted for filtering dual side-band SCM headers. Another optical filtering method is known using an optical loop mirror incorporating a birefringent fiber. This method can simultaneously extract multiple headers on multiple wavelengths, but it requires a very precise design of a bulky loop mirror filter. In addition, insufficient attenuation between the SCM and the baseband signal due to a very narrow notch filter bandwidth is a key obstacle for the fiber loop mirror method. Moreover, both the known all-optical SCM filtering methods have sinusoidal spectral transmission functions. This prevents such filtering methods from being used in Dense Wavelength Division Multiplexing (DWDM) applications wherein there are multiple signal of varying, though closely spaced, wavelengths, which all must be separated from their respective headers simultaneously.

[06] What is needed is a practical optically-compatible technique for extraction of subcarrier multiplexed (SCM) signal from a modulated baseband optical signal, routing of the baseband signal on the basis of the data contained in the SCM signal, and rewriting a new SCM signal on the old baseband signal for further processing.

SUMMARY OF THE INVENTION

[07] According to the invention, a method and an apparatus are provided for extraction of subcarrier multiplexed (SCM) signals such as optical header labels from a SCM/mixed baseband optical signal. The method provides further for the routing of the baseband optical signal in accordance with the information contained in the SCM signal and for the remodulation of the baseband signal to add a new SCM component. The method comprises applying an SCM/mixed baseband signal to a fiber Bragg grating (FBG) filter from which is extracted a modulated signal at information bandwidth limited photoreceivers tapped to an optical signal path via an optical circulator (OC), causing the SCM optical signal to be stripped from the baseband optical signal. After the SCM has been extracted from the SCM/mixed baseband signal, the remaining baseband signal is routed according to the information contained in the SCM signal, and it can be re-modulated to add a new SCM signal.

[08] The invention provides a polarization-independent and dispersion-insensitive all-optical technique for extracting an SCM signal, and it permits the implementation of practical all-optical Optical Label switching.

[09] The invention will be better understood by reference to the following detailed description in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[10] Figure 1 is a block diagram of an optical subcarrier receiver according to the invention, and it incorporates illustrations of the optical spectrum associated with each input port, output port and signal extraction port of the invention.

[11] Figure 2 is a block diagram showing an optical router that extracts an SCM header from a baseband data payload and based on the data contained in the SCM header, changes the wavelength of the baseband signal, routs the baseband signal through an array waveguide grating acting as a wavelength switch, and rewrites a new optical header.

DETAILED DESCRIPTION OF THE INVENTION

[12] Referring to Figure 1 there is shown an optical subcarrier receiver 10 comprising an optical circulator 12, a fiber Bragg grating 14, an optical energy transducer 16 such as a photodetector, and associated signal detection electronics. This may include an a.c. coupling capacitor 18, an electric lowpass filter 20 and an electric output amplifier 22 which together form a simple square law detector, also known as an envelope detector, for detecting the amplitude modulation on the signal received at the photodetector. Other forms of detection will be evident to those of skill in the art.

[13] Input 38 to the receiver is a subcarrier multiplexed baseband optical signal 24 which includes a modulated optical carrier 26 for a payload 28 and a modulated optical subcarrier 30 for carrying control information, such as header information for routing packet traffic on an optical network where signals are routed through the optical circulator 12 from its input 38 to its output 40. The modulated optical subcarrier 30 is doubled sideband modulated at a subcarrier frequency 32 relative to the frequency of the carrier 26 which is greater than the modulation bandwidth 34 of the optical carrier and the information bandwidth 36 of the subcarrier 30.

[14] In a specific embodiment, the fiber Bragg grating (FBG) 14 receives input from an extraction port 42 of the optical circulator 12 with higher than 99.95 % peak reflectivity with a pass band below 10 GHz full width at half maximum. The FBG 14

according to the invention is a compact package that may be temperature compensated to minimize drift in the peak wavelength with age and ambient conditions. Both the FBG wavelength, selected to separate the subcarrier 30 and the carrier 26 wavelengths in a typical embodiment may have the carrier centered close to the wavelength of 1560.1 nm. The structure in Fig. 1 allows reflection of a data payload, namely the modulated subcarrier 28, as indicated as a suppressed modulated carrier 26' at the output of the FBG 14 as well as transmission of the subcarrier 30 containing control or header information by the FBG 14. The two signal components are easily separated by using the optical circulator 12 to pass only the modulated carrier 26 through the output 40 of the circulator 12.

[15] In another embodiment an optical modulation means is coupled to the output 40 of the subcarrier receiver in order to encode a new SCM header onto the retained data payload. In a specific embodiment this optical modulations comprises a 10 Gb/s LiNbO3 Mach Zender modulator coupled to a programmable pulse generator but other forms of modulating an optical signal will be evident to those skilled in the art.

[16] Referring to Figure 2, there is shown a wavelength converting, optical label switching, optical packet router comprising an input 45, a subcarrier receiver as depicted in Figure 1, a forwarding table and controller 49, a rapidly tunable laser 50, a semiconductor optical amplifier 51, an array waveguide grating 52, and an array of header rewriters 53_1 - 53_8 and an array of corresponding outputs 54_1 - 54_8.. The subcarrier receiver itself comprises an optical circulator 46 with one input port and two output ports, a fiber Bragg grating (FBG) arranged at one output port to the circulator and a header detector, which is an optical to electrical transducer for detecting and converting the optical signal into an electrical signal. In one specific embodiment, the header detector comprises a photodetector coupled to a capacitor, a low pass filter, and an amplifier. Other optical detection devices will be evident to those skilled in the art.

[17] Input 45 to the router is a subcarrier multiplexed baseband optical signal which includes a modulated optical carrier for a payload and a modulated optical subcarrier for carrying control information, such as header information for routing packet traffic on an optical network. The signal is applied by the optical circulator 46 to the FBG 47. The FBG reflects the data payload signal and transmits the SCM header signal to the header detector 48. The header detector 48 is coupled to a forwarding table and controller 49 which determines the new destination and wavelength of the routed data signal.

[18] Based on the header information extracted by the subcarrier receiver, control signals are sent to a rapidly tunable laser 50 which is adjusted so that it emits light of

a wavelength indicated by the header information. In one specific embodiment the tunable laser supports a 45nm range between 1525nm and 1570nm. The output from the tunable laser 50 is directed to a semiconductor optical amplifier (SOA) 51. The modulated carrier signal for data payload from the optical subcarrier receiver is also directed to the SOA 51 such that it propagates through the SOA's gain medium in a direction opposite the direction of propagation of the light emitted by the tunable laser. This counter-propagating geometry avoids the need for using an optical filter for transmitting tunable laser output, and also provides additional bandwidth limit to further reduce leakage of the subcarrier header at the higher modulation frequency. Other means of modulating the tunable source's output such that it becomes proportional to the modulation of the data signal are possible. For example, in another specific embodiment, the inversion of the data payload modulation resulting from the counter propagating geometry is corrected by cascading another inverting wavelength converter not shown in tandem with the first SOA 51.

[19] The output of SOA 51 is coupled to an input of an array waveguide grating (AWG) 52. The AWG 52 is a device for dividing the optical power of a signal at an input port among a plurality of output ports in accordance with the spectral content of the input signal. Illuminating an input port of an AWG with a spectrally broad signal will result in light of different wavelengths being emitted simultaneously at a plurality of corresponding outputs. Illuminating an input port of an AWG with a spectrally narrow source can result in light being emitted at as few as one AWG output ports. When used with very narrow spectral sources, an AWG acts as a wavelength switch, directing light from an input to a specific output depending on the wavelength on the input light. In one specific embodiment, an AWG with 8 inputs and 8 outputs is used. Other types of AWGs and other types of wavelength switches will be evident to those of reasonable skill in the art.

[20] The combination of a the tunable laser 50 and the AWG 52 allows the data payload signal to be switched among the various outputs of the AWG as dictated by the information contained in the subcarrier header.

[21] In one specific embodiment, the AWG outputs are each coupled to header rewriters 53_1-53_8. In one embodiment, the header rewriters are LiNbO3 modulators coupled to signal generating electronics. The header rewriters 53_1-53_8 receive data from the forwarding table and controller 49 and write new SCM header information onto the switched data payload signal in accordance with the data content of the original header. After acquiring new header information, the switched signal propagates out of the router along one of a plurality of outputs 54_1-54_8.

[22] The invention have been explained with reference to specific embodiments. Other embodiments will be evident to those of ordinary skill in the art. It is therefore not intended that this invention be limited, except as indicated by the appended claims.